Finite Element Simulation of Orthogonal Hard Machining

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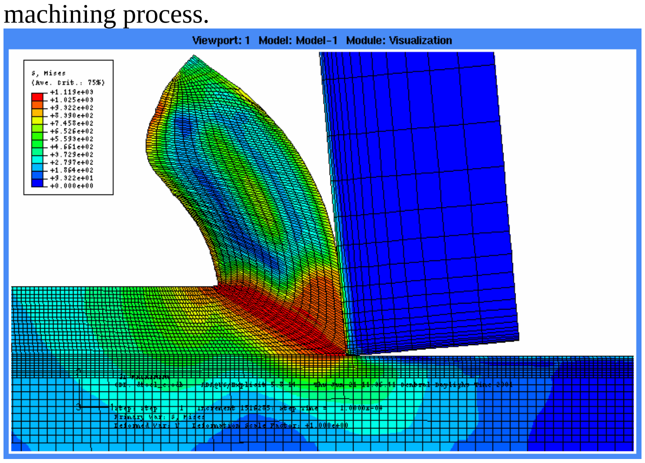
From a machining standpoint, materials with a hardness greater than 45 R_c are classified as "hard". Components made from these materials are usually finish machined by grinding. The advent of Polycrystalline Cubic Boron Nitride (PCBN) cutting tools has however opened up turning as a finish machining option. Parts produced by hard machining have been found to be comparable in quality to ground parts. This coupled with lower equipment costs and environmental acceptability make hard turning a more attractive option than grinding.

The main stumbling block that hard turning faces before industry acceptance is the generation of undesirable surface artifacts known as white layers generated during the machining operation. It is the accepted belief that white layers are detrimental to fatigue life of the component. Evidence from hard turned parts with white layer that have been fatigue tested shows the opposite. There has been no effort to systematically assimilate the effects of workpiece and tool material properties and cutting variables to predict temperature, stresses, resulting microstructures and therefore residual stresses in one work.

In order to achieve the objective of the research, the following tasks are to be completed:

<u>Thermo-mechanical modeling of orthogonal machining:</u>

A fully coupled thermo-mechanical finite element (FE) model has been developed in order to simulate the machining process.



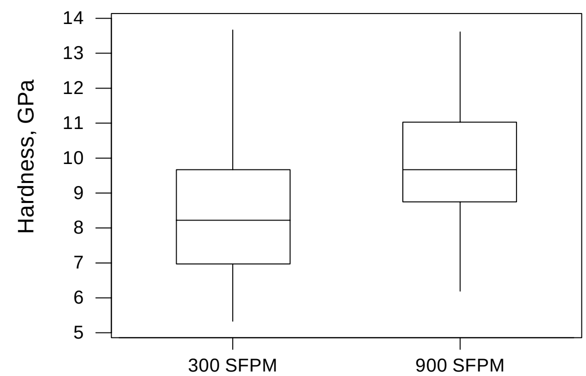
A contour plot showing effective stress during machining of AISI 4340 steel. Machining conditions are 3 m/s cutting speed, mm feed, -5^0 tool rake angle.

A fully-coupled, explicit updated-Lagrangian code (ABAQUS/Explicit®) has been used for this purpose. Chip separation has been modeled using an "effective plastic strain" criterion, whereby elements ahead of the tool tip fail if a critical strain is reached. Tool-chip and tool-work interaction has been modeled using Coulomb friction.

<u>Analysis of white layer formation:</u>

The nature of white layer formation in machining is not completely understood. It is unclear as to whether it is formed by grain refinement (intense mechanical deformation) or by retransformation (high temperature). In order to understand this, samples were machined at 300 SFPM and 900 SFPM from AISI 52100 steel (62 R_c) to isolate the above effects. Transmission electron microscopy (TEM) studies are currently underway to pinpoint any structural differences in white layer generated under the above conditions. Preliminary results show a difference in structure between the above white layers.

In addition to TEM, nano-hardness testing was also performed on taper sections of white layers generated at 300 and 900 SFPM. The results are shown below:



Boxplots showing comparison of nanohardness of white layer generated during machining of AISI 52100 steel.

It is proposed to model white layer formation in the retransformation regime in a manner similar to quenching. This is an analytical approach, which will be coupled to the thermo-mechanical model to give a complete description of the hard machining process.

<u>Modeling of residual stresses:</u>

This involves relaxing boundary conditions in the FE model and then simulating cooling of the workpiece to room temperature. Stresses thus present in the workpiece are those residual from the machining operation.

<u>Model validation:</u>

Presence and depth of white layer and residual stresses present on the workpiece surface generated under different speeds and feeds will be the primary variables for validation. Intermediate variables such as forces will also be monitored.

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